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Beam Position Monitors for the Cornell Electron Synchrotron*

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Abstract

The Cornell 10-GeV Electron Synchrotron, built in 1968 for fixed-target physics, has served since 1979 as injector to the storage ring CESR. In this mode, which calls for a sparse fill pattern (45 bunches at most), the original beam position monitors are ineffective. An improved system, now under construction, is described.

1 INTRODUCTION

Originally, the Cornell Electron Synchrotron accelerated a "continuous" beam (all 700 MHz RF buckets filled); its beam detectors used ferrite-core current transformers that could not resolve individual bunches. The cores carried auxiliary differential windings that served as rudimentary beam position monitors (BPMs). However, with the widely spaced bunches called for by CESR, these windings no longer deliver useful signals. New BPMs are being installed as part of a general improvement program.

With cost and downtime as major constraints, we decided that the new BPM system should fit into the present vacuum enclosures and work through the existing cable system. Analog signals representing intensity, horizontal, and vertical position are brought to the control room through three 75 Ω cables that encircle the synchrotron (~756 m circumference). These cables, similar to RG59/U but triaxially shielded, have an uncomfortably long risetime ($t_r \approx 70$ ns, maximum).

The BPM signals, after treatment by local preamplifiers, are multiplexed into the cables via small relays that are energized one at a time. Taking data for the complete ring requires stepping sequentially through all the relays.

BPMs for the synchrotron, as opposed to the storage ring, must deal with some special features: (1) The beam is about three orders of magnitude smaller—only a few times 10^8 particles per bunch—and it is not steady. (2) The orbit errors change during the acceleration cycle because remanent fields and eddy currents, important at injection time, become insignificant at high energy: orbit measurement must thus take place in a selected short time interval within the 8 ms acceleration cycle. (3) Coherent beam oscillations, caused principally by injection errors, remain significant throughout the acceleration cycle: the BPM signals must be averaged over several turns to locate the equilibrium orbit.

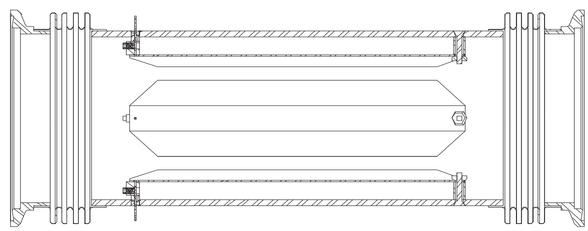

Figure 1. Vertical section through the stripline beam detector. e^- travel from right to left in this diagram, delivering at the downstream end of the stripline a pulse doublet with initially positive excursion. (e^+ moving in the opposite direction produce a similar signal.)

2 BEAM PROBES

Short beam probes (pickup "buttons" or loops) have capacitive or inductive source impedances. When loaded by a resistance R, such probes pseudo-differentiate the bunch signal. The time constants ($\tau = RC$ or L/R) come out well below 1 ns when $R \approx 50\ \Omega$. Since this is comparable to the duration of the bunch, the output signal becomes a short, bipolar pulse *doublet*. When such a doublet encounters a long risetime t_r, the output amplitude goes as $1/t_r^2$. In our case the signal would be reduced almost to the noise level. We avoid this by immediately converting the probe signal into a longer, monopolar pulse, using peak rectification by a fast diode.

A strip-line probe is better than a short probe in this mode of operation. Instead of pseudo–differentiating, the line adds a delayed, inverted reflection from its far end (shorted). The resulting doublet spacing can be large—twice the propagation time of the line. To fit into

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the available space, our lines are 0.15 m long, yielding a doublet spacing of 1 ns.

Between the 96 pairs of synchrotron magnets mounted on I–beams there are drift spaces (usually 0.28 m long) that alternately accommodate pump ports and corrector coils. The latter, assembled on a tube of 43 mm inner radius, leave enough clearance for BPM signal feed-throughs. The lattice functions β_x and β_y are approximately equal (~12 m) at these locations, giving similar sensitivities to the BPMs in both planes. The betatron tunes are $Q_x = 10.65$, $Q_y = 10.77$; we expect to install about 50 BPMs, spaced roughly by quarter–wavelengths.

Figure 1 shows one BPM consisting of four strip lines placed in symmetrical pairs on opposite sides of the beam in each dimension, horizontal (x) and vertical (y). The strip, spaced 9.5 mm from the wall of the tube, is 38 mm wide, yielding $Z_0 \approx 100\ \Omega$. (The strips are lightly folded longitudinally to conform to the curvature of the tubular wall.)

3 SIGNAL PROCESSING

To first order, the amplitudes from the two probes of a pair are, respectively,

$$a_+ = qk_+\left(1 + \frac{x}{x_0}\right) \quad \text{and} \quad a_- = qk_-\left(1 - \frac{x}{x_0}\right),$$

where q is the bunch charge, k_+, k_- are gain factors, x is the bunch displacement from center, and x_0 is a scale length. [Similarly for y.] In the ideal case we have $k_+ = k_-$; then

$$x = \frac{\Delta a}{\Sigma a}\, x_0,$$

with $\Delta a \equiv a_+ - a_-$ and $\Sigma a \equiv a_+ + a_-$. To ensure that a null Δ–signal correctly indicates $x = 0$, we evidently need to maintain $k_+ = k_-$ over an adequate dynamic range.

Unfortunately, pulse stretching (by peak rectification) cannot be done *after* the Δ–signal is formed, since this signal may have either sign. The two line signals must therefore be rectified individually, with the two rectification yields entering separately into k_+ and k_-. As illustrated in Fig. 2, the main feature of diode rectification is a threshold intercept, governed by the diode's cut–in voltage. With our particular strip lines and diodes (Hewlett–Packard HP5082–2835 in the prototype), this threshold corresponds to ~10^7 particles per bunch; above threshold the rectification yield is substantially linear. We will use matched pairs of diodes for each pair of strip lines; when the intercepts are equal a null Δ–signal still correctly indicates $x = 0$. To calculate a nonzero bunch displacement from the stretched signals we use

$$x = \frac{\Delta a}{\Sigma a + 2a_0}\, x_0,$$

where a_0 is the threshold intercept projected onto the pulse amplitude axis (see Fig.2).

If a small gain mismatch does remain, suppose that

$$k_+ = (1 + \varepsilon)\, k_- \qquad [\varepsilon << 1].$$

A centered bunch then yields $\Delta a/\Sigma a \approx \varepsilon/2$, giving a false indication

$$x_\varepsilon \approx (\varepsilon/2)\, x_0.$$

With $x_0 \approx 21$ mm, to hold $x_\varepsilon \leq 1$ mm—adequate for our purposes—we need only maintain $|\varepsilon| \leq 9\%$.

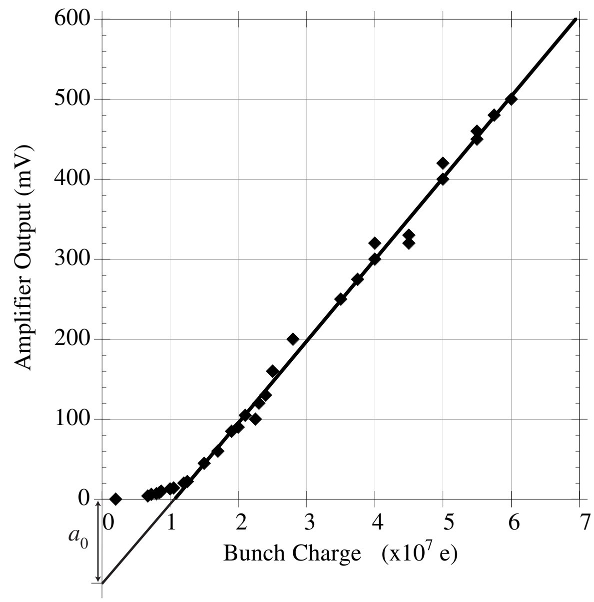

Figure 2. Amplifier output as a function of bunch charge. A linear fit to the data above threshold is shown.

4 CIRCUITS

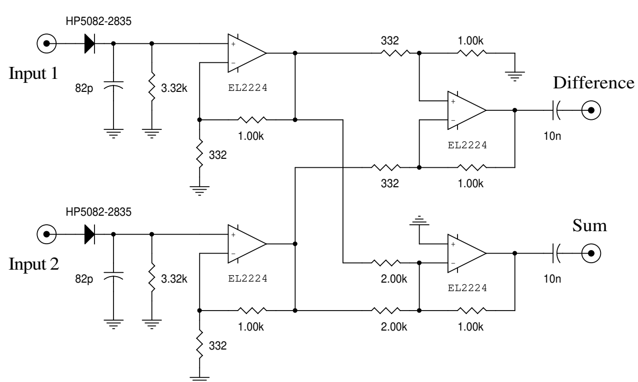

Figure 3. Schematic of prototype stretchers, sum, and difference amplifiers for one pair of striplines. (To avoid reaching the amplifier's output current limit, the sum channel has a lower gain than the difference channel.)

Figure 3 shows the arrangement of stretchers and amplifiers for forming Δa and Σa and driving the coaxial cables. Figure 4 shows the Δ–signal observed through the coaxial cable. A high–pass time constant of 0.4 µs, well below the 2.5 µs revolution period, ensures that the signal returns to zero between pulses. (Orbit measurements will be made with only a single bunch of e^- circulating.)

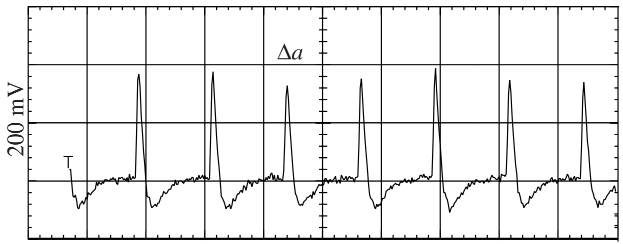

Figure 4. Delta–signal from a vertical pair of striplines, seen ~4 ms into the acceleration cycle. A substantial offset of the equilibrium orbit is indicated, as well as some bunch oscillations.

Starting at the desired time in the acceleration cycle, BPM pulses from a selected group of turns must be integrated to obtain the *average* bunch position (in the presence of oscillations). This is illustrated, for 5 turns, in Fig. 5. The burst of 5 gate signals is timed so as to exclude the reverse–polarity excursion of each BPM pulse. The gate output is applied to an operational integrator, which is reset before the burst but allowed to hold its accumulated voltage until read out by a computer.

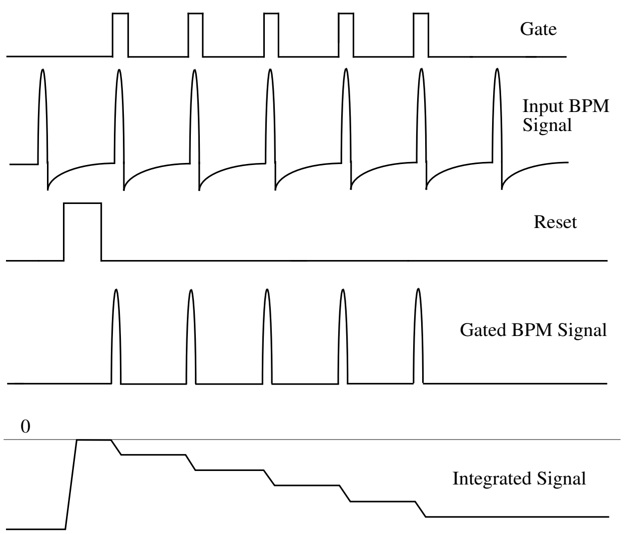

Figure 5. Timing diagram for the gated integrator circuit. (The integrator reverses the signal polarity.)

5 CALIBRATION

A rough estimate for x_0 (≈ 21 mm) was obtained in bench measurements, using a short pulse sent down a movable conductor to simulate the beam. A more appropriate calibration will be obtained, in due course, during studies of the orbit–correcting procedures themselves.

6 CONCLUSION

A stripline BPM, together with its signal processing circuits, has been designed and tested with good results. Slight modifications to these designs will be made, but a suitable system is close to reality. During the 1999 summer shutdown, in preparation for CESR Phase III high–current running, the synchrotron will be completely outfitted with this BPM system.

7 ACKNOWLEGMENTS

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